Evolution of Tropical Cyclone Characteristics

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LONG-TERM GOALS

The long-term goals are to understand how variabilities in the large-scale atmospheric environment and the internal tropical cyclone structure influence tropical cyclone track and intensity characteristics and define how these influences differ between developing, mature, and decaying tropical cyclones. During the initial stages of tropical cyclone development, structure and track characteristics can exhibit large variabilities that pose difficult forecast situations. Because decaying tropical cyclones often transition to fast-moving and rapidly-developing extratropical cyclones that may contain gale-, storm-, or hurricane-force winds, there is a need to improve understanding and prediction of the extratropical transition (ET) phase of a decaying tropical cyclone. Therefore, a tropical cyclone throughout its life cycle has the potential for impacting many fleet units. As increased understanding leads to improved forecasts of tropical cyclone motion and structure characteristics, a secondary long-term goal is to assess the utility of the tropical cyclone forecast products to shore- and sea-based assets.

OBJECTIVES

Recent research has concentrated on two primary objectives. Extended periods of increased and reduced tropical cyclone activity occur several times during a typical tropical cyclone season (Harr and Elsberry 1991;1995a,b). An objective of this project is to identify the physical mechanisms in the large-scale circulation that act to initiate, maintain, and decay periods of enhanced or reduced tropical cyclone activity. If reliable forecasts of extended periods of increased or reduced tropical cyclone activity could be made, maritime operations could be coordinated appropriately.

Because of the increased need for tropical cyclone forecasts at intervals beyond 72 h, it is possible that a tropical cyclone may form and move a long distance during any given forecast sequence. Because numerical forecast guidance tends to be less accurate during the early stages of the tropical cyclone life cycle, an objective is to identify the capability of operational numerical models to identify circulations that will eventually develop into tropical cyclones.

APPROACH

Variability in the large-scale circulation over the western North Pacific is placed into a hierarchical framework of global-scale intraseasonal, regional-scale monsoon trough, and synoptic-scale variability. Low-level wind fields and outgoing longwave radiation (OLR) characteristics are then partitioned into contributions from the various modes. Relationships among the three modes are examined to identify factors that explain variability in tropical cyclone activity/inactivity.

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14. ABSTRACT
The long-term goals are to understand how variabilities in the large-scale atmospheric environment and the internal tropical cyclone structure influence tropical cyclone track and intensity characteristics and define how these influences differ between developing, mature, and decaying tropical cyclones. During the initial stages of tropical cyclone development, structure and track characteristics can exhibit large variabilities that pose difficult forecast situations. Because decaying tropical cyclones often transition to fast-moving and rapidly-developing extratropical cyclones that may contain gale-, storm-, or hurricane-force winds, there is a need to improve understanding and prediction of the extratropical transition (ET) phase of a decaying tropical cyclone. Therefore, a tropical cyclone throughout its life cycle has the potential for impacting many fleet units. As increased understanding leads to improved forecasts of tropical cyclone motion and structure characteristics, a secondary long-term goal is to assess the utility of the tropical cyclone forecast products to shore- and sea-based assets.

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A technique is derived to provide an automated catalog of forecast and analyzed circulations contained in a variety of operational numerical forecast models that are used to predict tropical cyclone formation and initial intensification. The technique is defined to allow assessment of both historical and real-time tropical cyclone formation potential in relation to each model's representation of various factors associated with tropical cyclone formation.

WORK COMPLETED

A Singular Value Decomposition (SVD) analysis has been applied to 850 hPa wind anomalies and OLR anomalies for the period 1979-1998. The SVD modes were used to define spatial and temporal characteristics of the western North Pacific large-scale circulation over intraseasonal (global in space and 30-60 days in time), monsoon trough (regional in space and 10-25 days in time), and synoptic scales. The results of the SVD analysis have been used to identify the contribution of each mode to total large-scale circulation variability, which was then related to tropical cyclone activity or inactivity.

A study was completed (Klein et al. 2002) of the sensitivity of the two-stage process (Klein et al. 2000) of ET to the interaction between the tropical cyclone and the midlatitude circulation into which the tropical cyclone is moving. The sensitivity was examined by modifying the initial conditions of several simulations using the Coupled Ocean Atmosphere Mesoscale Prediction System (COAMPS) such that the movement of the tropical cyclone into the midlatitudes was either delayed or accelerated and thus altered the phasing with the midlatitude circulation.

To examine the capability of operational numerical models to identify circulations that may become tropical cyclones, an algorithm has been developed to detect and track circulations throughout the forecast sequence. A matching technique was used to associate predicted circulations with the verifying analyzed circulation plus identify analyzed circulations with various environmental parameters (i.e., satellite-based cloud properties).

RESULTS

Previous results (Harr and Elsberry 1995a,b) have related tropical cyclone activity over the western North Pacific with the sign of zonal wind anomalies associated with the monsoon trough. Positive (westerly) anomalies are associated with an active monsoon trough and with enhanced tropical cyclone activity. Negative (easterly) anomalies define an inactive monsoon trough and reduced tropical cyclone activity. Based on the SVD analysis (Harr and Elsberry 2002), intraseasonal modes related to the Madden-Julian Oscillation (MJO) were identified with an enhanced or reduced monsoon trough (Fig. 1). Therefore, the amount of variability in tropical cyclone activity that could be associated with the MJO was identified based on 30-60 day filtered zonal wind anomalies along the southern periphery of the monsoon trough (Fig. 2). Approximately 40% of the tropical cyclones that occurred over the western North Pacific during June-October 1979-1998 formed when 30-60 day mode of variability was associated with a reduced monsoon trough. Therefore, the relationship between the intraseasonal mode and tropical cyclone activity was not strong enough to have predictive skill when the 30-60 day zonal wind anomalies are used as a measure of the strength of the monsoon trough.

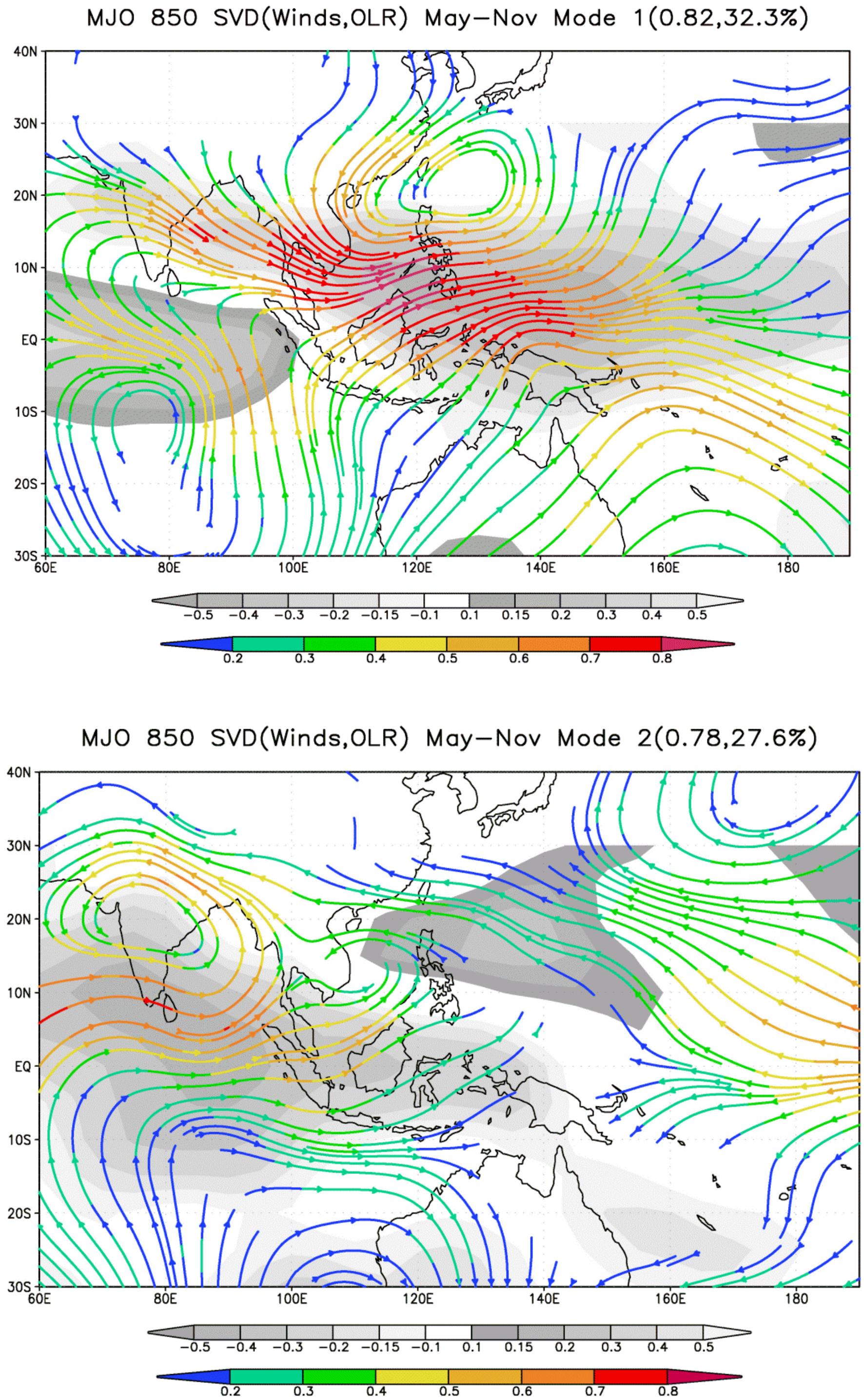


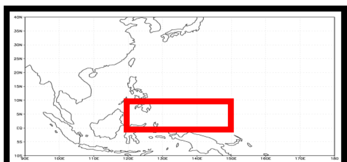
Figure 1.

Heterogeneous correlation maps (top: mode 1, bottom: mode 2) defined from the SVD analysis of 850 hPa wind anomalies and OLR anomalies between April-November 1979-1998. Gray-shaded areas define OLR correlations such that light-to-dark defines enhanced convection and dark-to-light defines reduced convection. Wind correlations are depicted by color-coded streamlines such that westerly anomalies would be associated with positive correlations. The total correlation and percent covariability associated with each mode are defined in the parentheses above each panel.

To account for a larger portion of the variance in tropical cyclone activity, the 10-25 day mode was examined in relation to variability of the monsoon trough. The spatial modes of 10-25 day variability are dominated by southeast-to-northwest moving circulations that are of a larger spatial extent than synoptic-scale circulations. Furthermore, a major component of the 10-25 day Modes is cross-equatorial flow from (to) the Southern Hemisphere during periods of an enhanced (reduced) monsoon trough. A significant amount of tropical cyclone activity that occurred during periods when the 30-60 day monsoon trough components was inactive was associated with periods when the 10-25 day mode of variability was larger than the 30-60 day mode and oriented such that the 10-25 day monsoon trough was active. Therefore, a combination of the two modes is required to explain a significant portion of the tropical cyclone activity.

Table 1

Frequency of tropical cyclone occurrence over the western North Pacific during June-October 1979-1998 stratified by 30-60 day zonal wind anomalies averaged over the region defined by the box in the upper-left portion of the table. Table columns define sub-regions of the western North Pacific as South China Sea (Eq.-20N, 100-120E), Monsoon Trough (Eq-20N, 120-150E), East of the Monsoon Trough (Eq.-20N, 150-180E), and North of the Monsoon Trough (20-30N, 110-160E).



	South China Sea	Monsoon Trough	East of the Monsoon Trough	North of the Monsoon trough	Total
30-60 day zonal wind > 0	28	128	51	35	242
30-60 day zonal wind < 0	18	82	35	31	166

Analyzed and forecast 850 hPa vorticity associated with circulations over the North Atlantic and western North Pacific in the Navy Operational Global Atmospheric Prediction System (NOGAPS) have been examined and catalogued with a new tracking procedure (Dorics et al. 2002). The procedure defines each circulation in terms of a bivariate-normal probability ellipse (Fig. 2). This representation then defines a basis for calculation of various physical quantities such as circulation size, orientation, motion, and amplitude. Various factors associated with tropical cyclone formation (e.g., analyzed and forecast vertical wind shear) are also computed with respect to the probability ellipse representation of the circulation. This tracking procedure has been applied to several operational models to develop a knowledge data base that defines the capability of each model to accurately predict tropical cyclone formation at forecast ranges to
120 h.

IMPACT/APPLICATIONS

Identification of the interactions between various modes of tropical circulation variability will lead to a statistical forecast scheme of extended periods of tropical cyclone activity/inactivity. If reliable forecasts of extended periods of inactivity (i.e., at least 20 days with no tropical cyclones) could be made, maritime operations could be coordinated to take advantage of the period of reduced threat from tropical cyclones.

The new tracking algorithm will impact analysis of the factors associated with successful and unsuccessful forecasts of tropical cyclone formation for a suite of operational numerical forecast models. Knowledge of the potential for each operational numerical forecast model for prediction of tropical cyclone formation will lead to a consensus technique for identifying the probability of tropical cyclone formation.

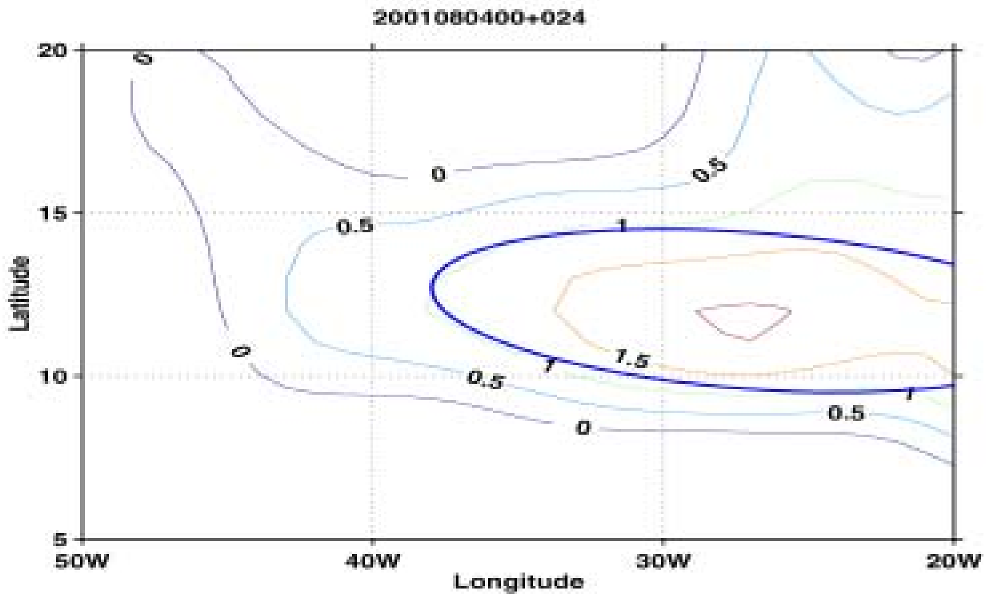


Figure 2.
A 24-h forecast of positive relative vorticity at 850 hPa over the North Atlantic (light contours in units of 10^{-5} s^{-1} and the representation of the circulation by the 95% level of the bivariate normal probability ellipse fit to the contour value of $1*10^{-5}$ s^{-1}.

TRANSITIONS

It is anticipated that an operational forecast scheme of intraseasonal variability in tropical cyclone activity will be based on the research results from this project. An operational assessment of the potential for analyzed and forecast circulations to develop into tropical cyclone will be developed by utilizing the tracking algorithm to categorize and verify circulation characteristics in a suite of operational models.

RELATED PROJECTS

This project is related to the project titled "Predicting Tropical Cyclone Formation and Structure Change" under Principal Investigators R. L. Elsberry, and P. A. Harr. Research conducted under the project described in this summary will be applied to the development of an knowledge-based expert system to allow Joint Typhoon Warning Center (JTWC) forecasters to make more accurate and consistent forecasts of tropical cyclone formation and structure.

SUMMARY

During the next year, results from the examination of the interaction between modes of tropical circulation variability will provide a sound forecast system for assessment of tropical cyclone activity that may be expected over ranges between 10-25 days. Finally, the assessment of the capability of each operational numerical model to predict tropical cyclone formation will provide operational forecasters with information to efficiently assess model guidance.

REFERENCES

Harr, P. A., and R. L. Elsberry, 1991: Tropical cyclone track characteristics as a function of large-scale circulation anomalies. *Mon. Wea. Rev.*, **119**, 1448-1468.

Harr, P. A., and R. L. Elsberry, 1995a: Large-scale circulation variability over the tropical western North Pacific. Part I: Spatial patterns and tropical cyclone characteristics. *Mon. Wea. Rev.*, **123**, 1225-1246.

Harr, P. A., and R. L. Elsberry, 1995b: Large-scale circulation variability over the tropical western North Pacific. Part II: Persistence and transition characteristics. *Mon. Wea. Rev.*, **123**, 1247-1268.

Harr, P. A., and R. L. Elsberry, 2000a: Extratropical transition of tropical cyclones over the western North Pacific. Part I: Evolution of structural characteristics during the transition process. *Mon. Wea. Rev.*, **128**, 2613-2633.

Klein, P. M., P. A. Harr, and R. L. Elsberry, 2000: Extratropical transition of western North Pacific tropical cyclones: An overview and conceptual model of the transformation stage. *Wea. Forecasting*, **15**, 373-395.

Klein, P. M., P. A. Harr, and R. L. Elsberry, 2002a: Extratropical transition of western North Pacific tropical cyclones: Midlatitude and tropical cyclone contributions to re-intensification. *Mon. Wea. Rev.*, **130**, 2240-2259.

PUBLICATIONS

Dorics, T., P. A. Harr, and R. L. Elsberry, 2002: Assessment of the potential for prediction of tropical cyclone formation in the Navy global model, *Preprints, 25th Conference on Hurricanes and Tropical Meteorology*, Amer. Meteor. Soc., Boston, MA 02108, 222-223.

Harr, P. A., and R. L. Elsberry, 2002: Prediction of intraseasonal variability in tropical cyclone activity over the western North Pacific Ocean. *Preprints, 25th Conference on Hurricanes and Tropical Meteorology*, Amer. Meteor. Soc., Boston, MA 02108, 654-655.

Jones, S. C., P. A. Harr, J. Abraham, L. F. Bosart, P. J Bowyer, B. N. Hanstrum, M. R. Sinclair, R. K. Smith, and C. Thorncroft, 2001: The extratropical transition of tropical cyclones: Forecast challenges, current understanding and future directions. *Wea. and Forecasting*, Revised version submitted.

Klein, P. M., P. A. Harr, and R. L. Elsberry, 2002a: Extratropical transition of western North Pacific tropical cyclones: Midlatitude and tropical cyclone contributions to re-intensification. *Mon. Wea. Rev.* **130**, 2240-2259.

Klein, P. M., P. A. Harr, and R. L. Elsberry, 2002b: Extratropical transition of western North Pacific tropical cyclones: Midlatitude and tropical cyclone contributions to re-intensification. *Preprints, 25th Conference on Hurricanes and Tropical Meteorology*, Amer. Meteor. Soc., Boston, MA 02108, 541-542.